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Low carbon-based energy strategy for transportation sector development

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ABSTRACT

This study presents the development of various scenarios for energy planning for the transportation sector. The case study in this paper is the transportation system in the Yogyakarta Province of Indonesia. The transportation sector has the highest energy demand of all the other sectors in this province. Therefore, this sector is a significant contributor to greenhouse gas emissions. Four scenarios were developed, business as usual, mode change, fuel switch and efficient vehicle. The business as usual scenario is the reference scenario. Also, a scenario, called the mitigation scenario, which combines the mode change, fuel switch and efficient vehicle scenarios was also developed. An analysis of the energy demand projections and greenhouse gas emissions, in the form of CO_2, NO_x, and CH_4, was conducted and the contribution of the aforementioned scenarios to low-carbon energy planning for the transportation sector was analyzed.

Long-range energy alternative planning software was utilized to simulate the scenarios. The efficient vehicle scenario resulted in the highest reduction in energy demand. At the end of the projection period, this scenario reduced energy demand for the transportation sector by 15.82% compared to the reference scenario. The mitigation scenario reduced energy demand by 20.45% compared to the reference scenario in 2050. By implementing an efficient vehicle scenario, global warming potential can be reduced by 15.80%. The implementation of the mitigation scenario reduced global warming potential by 24.76% compared to the reference scenario.

Keywords:

Transportation sector;
GHG emission;
GHG mitigation;
Scenario development;

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1. Introduction

Yogyakarta is a province of Indonesia with high economic growth compared to other provinces. The growth in the gross domestic product (GDP) in Yogyakarta Province from 2011 to 2017 is about 5.0% [1]. This indicates the consistent economic growth that led to high urbanization and improved income per capita. Additionally, the growth of the population in Yogyakarta Province from 2010 to 2016 was about 1.18% which is considered a high growth rate in the population in Indonesia [2]. The combined factors of GDP and population growth also led to an increase in energy demand. Based on the regional energy outlook of Yogyakarta Province, the overall energy demand from this sector in 2015 was 34.02 PJ and this will continue to increase to 44.26 PJ in 2025. It has been predicted that over the period from 2015 to 2025, the energy demand in the transportation sector is 57.85% [3]. Furthermore, the transportation sector is the most significant contributor to greenhouse gas (GHG) emissions. A more complex problem arise because all energy is imported from outside of the province. Moreover, the fuel source is not available in the province. The only energy sources are in the form of renewable energy such as solar, wind,

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and biomass. The renewable energy source currently is not optimized to supply the energy need of the province.

The techno-economy approach was used in energy planning for the transportation sector using a case study on the transportation system in Iran in [4]. This study analyzed several scenarios compared to the reference energy system which substitutes railway technology, passenger vehicle technology, freight vehicle technology and uses compressed natural gas (CNG) for light and heavy trucks. These scenarios were implemented in the Energy Flow Optimization Model. This study showed that energy consumption could be reduced by 14%. Electric vehicles can play a greater role in reducing the GHG emissions caused by the transportation system [5]. This study showed that vehicle owners gain many benefits by driving electric vehicles.

The relationship between energy intensity and energy demand in the transportation sector is discussed in [6]. This study used a decomposition method of the Logarithmic-mean Divisia Index Method (LMDI) and showed that energy intensity plays a dominant role in the reduction of energy demand for the transportation sector. The LMDI method was also used to analyze carbon dioxide in the passenger and freight transport sector in China [7]. Based on this study, freight transportation increase in carbon dioxide emission reflecting the efficient way to reduce overall GHG emission in the transportation system.

A reduction in energy demand leads to a reduction in GHG emissions. The reduction in GHG emissions in the transportation system of Korea was analysed in [8]. The study considered five policies by which to reduce GHG emissions, these being: improved fuel efficiency, green car distribution, competitive green car distribution, public transportation shift, and modal shift reinforcement. By implementing these scenarios, energy demand reduced by 25.5% and GHG emissions were reduced by 21.6%. However, this study showed that the national level target could not be reached by reducing the GHG emissions produced by the transportation sector.

A reduction in energy demand and GHG emissions in the transportation sector was achieved by the implementation of a fuel mix policy in [9]. This study competed for three objective variables which are energy consumption, fuel subsidy, and CO_2 emissions. Implementing a retirement program for old vehicles was the most significant factor in reducing energy consumption and CO_2 emissions. This study found that the use of CNG in the transportation system had a less significant impact on the reduction of fuel consumption and CO_2 emissions. Decarbonizing the transportation system of Sweden was reported in [10]. Two scenarios were developed in this study which are a high percentage of electric vehicles and a high percentage of biofuels. The results showed that the lowest annual system costs were obtained by a high share of electric vehicles. The work in [11] investigated the decarbonization of the power and transportation sector in a residential area of Austin, Texas . The development of energy-related policies in the transportation sector was published in [12]. The relationship between variables and energy intensity was identified using document coding; then a fuzzy cognitive map was implemented to analyze the variables' impact on climate change. This study suggested that climate change policies should be implemented in the Turkish transportation system to reduce GHG emissions.

In addition to GHG emissions, particulate matter ($PM_{2,5}$) is one of the pollutants emitted by the transportation sector that must be considered. Policy development regarding the reduction of $PM_{2,5}$ and CO_2 emissions was reported in [13] in relation to India's transportation system. The results of this study can be used by Indian policymakers to quantify targets to reduce emissions generated by the transportation sector. Comprehensive policy developments to mitigate the GHG emissions from the transportation sector in Korea's transportation sector were published in [14] using a bottom-up energy model. This study found that the adaptation of new technology in the transportation sector could reduce GHG emissions by 30%. Four options for the energy strategy in the transportation sector were provided by this study. The possibility of a significant reduction in GHG emissions from the transportation sector was simulated in [15] based on modeling using a case study in New Mexico. An energy-efficient strategy was proposed in an energy strategy for the transportation sector to reduce energy demand and GHG emissions in [16]. The potential for energy efficiency in the transportation sector is very regional-dependent. Each province in China has different characteristics that resulted in different energy management policies being implemented in the transportation sector.

The contribution of this research is as follows:

1. This research proposes an analytical procedure to develop energy-related scenarios for the transportation sector,

2. Energy intensity and transportation activities are the primary variables to develop scenarios,
3. A bottom-up model is used in this research with the implementation of a real case in the transportation sector.

The work is based on the research of determination of energy intensity that will be used to predict the energy demand of transportation sector. The data of energy intensity, especially for transportation sector, is not available regionally. The case study of this research is a very small province compare to another province in Indonesia. It is a good start and may be replicated by another province. GHG analysis was also conducted in this paper. Business as Usual (BAU) scenario is applied to predict the energy demand and GHG emission based on existing state. Four alternative scenarios introduced energy saving to decrease GHG emission. This paper supports regional government effort to develop new energy strategy based on GHG intensity reduction.

2. Research methodology

Two kinds of energy models, top-down and bottom-up, can be used to investigate the potential of reducing an energy system's GHG emissions. The energy system includes the overall process from primary energy processing to final energy demand. The economic perspective is used in top-down models whereas the bottom-up model uses a systematic perspective to conduct energy system analysis. In combination with bottom-up models, energy technologies and energy sources can be selected by implementing optimization models to meet demands at minimum cost. In this study, Long-range Energy Alternative Planning (LEAP) software is utilized. LEAP, as an energy analysis tool, was developed by the Stockholm Environment Institute (SEI) [17].

2.1. LEAP model

The concept of LEAP is that users can use quantitative data on existing and projected demand [18]. LEAP is considered a good accounting framework of the energy demand-supply model. LEAP provides easy-to-use tools to input data sets and has been promoted in many studies [19]–[21]. In relation to GHG emissions, LEAP has the advantage of allowing users to design an energy forecast structure based on demand and supply data and is able to compare many different scenarios. The comparison provided by LEAP assists in the identification of policies which will have the most significant impact on energy efficiency and the reduction of GHG emissions [22]. Moreover, LEAP facilitates the design of environmental-related scenarios [23]. The analysis of scenarios is considered the main feature of LEAP.

Driver variables such as gross domestic product (GDP), population, number of households, economic structure, and transportation modes are entered into LEAP as key assumptions. Based on a specific data point, energy demand by sector can be forecasted based on the developed scenarios. The activity level of each sector or subsector, the energy production of the transformation sector, and the primary energy production rate are the main parameters of the LEAP model. The environmental impact of the energy sector is calculated by LEAP based on Tier 1 GHG emission factors of the global warming potential (GWP) of the fifth report of the inter-governmental panel on climate change (IPCC). GWP potential was implemented as a technology and environmental database (TED) inside the LEAP software to calculate the GHG emissions as air pollution. The results of calculating the emissions can be analyzed based on sector or subsector and fuel type. Each energy consumption and production has its own related TED of default emission factor based on IPCC to estimate and calculate the environmental impact of the energy sector.

To forecast energy demand, the LEAP demand module can be designed based on the available data set. There is no specific structure of the demand module. LEAP provides high flexibility to allow users to design energy demand by sector or subsector, technological energy used, or energy purpose. LEAP provides four methods to analyse energy demand: final energy intensity, useful energy, the analysis of the stock, and transport analysis.

2.2. Analytical procedure, data, and data sources

Energy consumption in the transportation sector in this study is evaluated in two steps. In the first step, two parameters of total transportation activity and the intensity of energy are calculated. Total transportation activity is represented as travel demand. Equation (1) calculates travel demand ($TD_{i,t}$) in passenger-km or ton-km. $V_{i,t}$ is the overall number of vehicles in category i, $AVT_{i,t}$ is the average annual vehicle travelled of each vehicle category i in kilometers, and $VOR_{i,t}$ is the occupancy rate of each vehicle category i in passenger kilometers per vehicle kilometer. t is the year index used in the LEAP. $V_{i,t}$ is dependent on population and GDP growth for passengers and cargo, respectively. The relation of $V_{i,t}$ and the growth of GDP and the growth of the population is described in (2) and (3) for passengers and cargo, respectively. ΔG and ΔP is the growth in GDP and the growth in the population respectively. e_i is the elasticity of each model of transportation to the growth of GDP and the growth of the population, respectively.

$$TD_{i,t}\,(\text{pass-km or ton-km}) = \sum V_{i,t} AVT_{i,t} VOR_{i,t} \quad (1)$$

$$V_{i,t} = V_{i,(t-1)}(1 + \Delta G * e_i) \quad (2)$$

$$V_{i,t} = V_{i,(t-1)}(1 + \Delta P * e_i) \quad (3)$$

The energy intensity ($EI_{i,j,t}$) of the transportation sector is calculated by (4). In this equation, $FE_{i,j,t}$ is the fuel economy for each fuel type j and each vehicle category i in vehicle kilometers per litre. This equation is also applied in each year t.

$$EI_{i,j,t}\,(\text{litre/pass-km or litre/ton-km}) = \sum_{i,j} \frac{1}{FE_{i,j,t}} VOR_{i,t} \quad (4)$$

The second step is to calculate the energy demand of the transportation sector ($ED_{i,t}$) by implementing equation (5). GHG emissions are calculated by equation (6) where $EF_{j,k,t}$ is the emission factor of pollutant type k for fuel category j in year t.

$$EI_{i,t}\,(\text{litre}) = \sum_{i,j} TD_{i,t} EI_{i,j,t} \quad (5)$$

$$Emission_t\,(CO_2\text{Eq}) = \sum_i \sum_k \sum_i ED_{i,t} EF_{j,k,t} \quad (6)$$

Data collection is an essential part of modeling to obtain a reliable model that can be accurately implemented. However, collecting complete and reliable data for all parameters and variables in LEAP is a challenging task due to a lack of integrated statistical data in Indonesia. Therefore, the data needed for LEAP modeling have been collected from several data sources. Data on driver variables such as GDP, population, and the number of registered vehicles was collected from the National Statistics Council of Indonesia. Data related to primary energy supply was collected from PERTAMINA, a national oil company in Indonesia. Electricity data was provided by PLN, a national electricity company in Indonesia.

Figure 1 illustrates the GDP and the GDP growth in Yogyakarta Province in Indonesia, showing the fluctuations in the growth of the GDP. In this model, the value of the GDP is a constant price based on the 2010 value. In 2017, the GDP of Yogyakarta Province was to "6.15 Billion USD. Population data is another drive variable that was collected from the National Statistics Council This data is shown in Figure 2. It can be seen that the growth in the population in Yogyakarta province

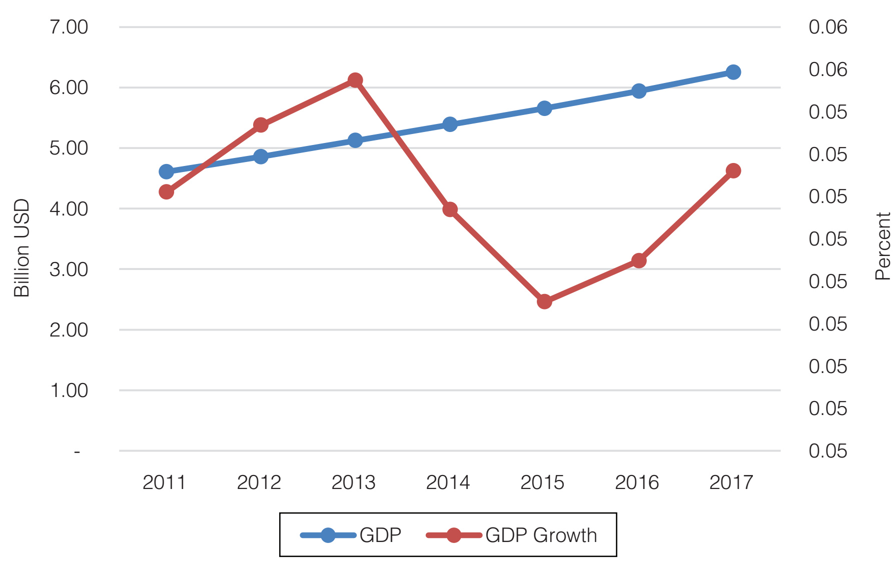

Figure 1: GDP and GDP growth in Yogyakarta Province. (source: National Statistics Council)
1 USD = 15,000 IDR

decreased by 1.11% in 2017. The population of Yogyakarta Province in 2017 was 3,762,214.

The total number of registered vehicles in Yogyakarta Province is shown in Table 1 and Table 2 shows the road and non-road transportation activities. The number of the registered vehicles has been taken from the National Statistics Council which is annually updated. Other variables in Table 1 have been extracted from the national survey of the transportation sector by the Ministry of Energy and Mineral Resources in Indonesia. Similar data sources were used to develop Table 2.

The transportation sector activity in Yogyakarta Province is represented as travel demand per passenger. This activity is projected from 2015 to 2050 based on the master plan for national energy demand in Indonesia. The transportation activity projections are based on the population and GDP projections. Linear regression was

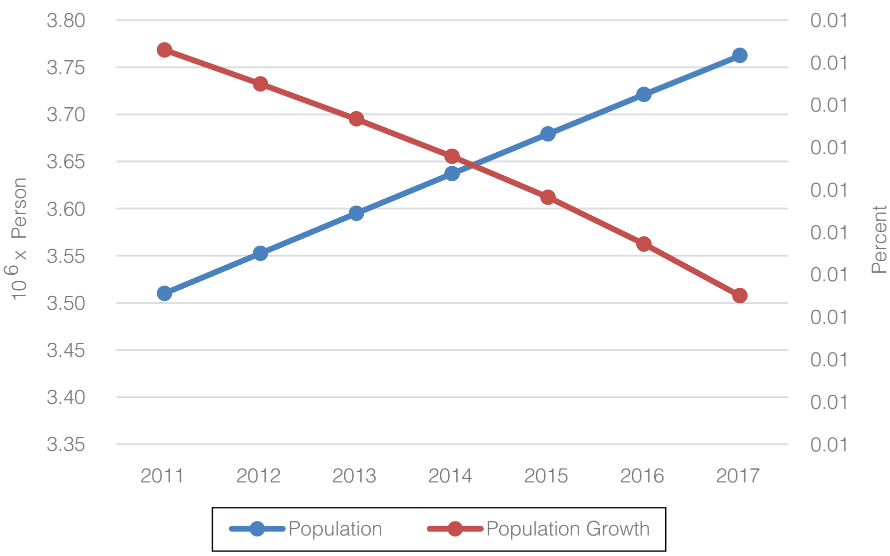

Figure 2: Population and population growth in Yogyakarta Province

Table 1: Total number of registered vehicles and related variables [24]

Types of Vehicle	**Fuel Share (%)**	**Total Registered Vehicles**	**Mileage (km)**	**Load Factor**	**Fuel Economy (km/l)**
Passenger Car		374,118	20,100	1.8	
- Gasoline	*94.30*				11.0
- Diesel	*0.70*				14.0
- BioDiesel	*5.00*				14.0
Bus		48,713	31,000	42.0	
- Diesel	*95.00*				6.0
- BioDiesel	*5.00*				6.0
Truck		158,994	31,000	8.3	
- Diesel	*93.00*				5.0
- BioDiesel	*7.00*				5.0
Motor Cycle		3,438,740	8,000	1.3	
- Gasoline	*100.00*				35.0

Table 2: Activities of the non-road transportation sector [24]

Types of Modes	Fuel Share %	Activity	Unit
Passenger Train		831.40	Million Pass-km
- Diesel	*100.00*		
Cargo Train		127.56	Million Ton-km
- Diesel	*100.00*		
Passenger Airplane		986.77	Million Pass-km
- Avgas	*0.03*		
- Jet Oil	*99.97*		
Cargo Airplane		94.92	Million Ton-km
- Jet Oil	*100.00*		

implemented in the LEAP to project the population and GDP of Yogyakarta Province. Based on this projection, the number of registered vehicles can be calculated based on (2) and (3) after which the travel demand in (1) can be projected. The activity of the transportation sector is used as the baseline scenario to which all the other scenarios refer. The annual vehicle travel is assumed to be constant for all scenarios along the projection period.

The types of fuel used in the transportation sector are mainly gasoline and diesel. Data on the GHG emissions caused by this fuel came from the database of the IPCC default factor of emissions for the transportation sector. The GHG investigated in this study are CO_2, CH_4, and NO_x. The emission factors of these gases are integrated into LEAP as TED. The global warming potential (GWP) unit (ton CO_2 equivalent) of these gases is used to express a similar impact on the environment [25].

3. Scenario development

This study considers the following four scenarios: business as usual, mode change, fuel switch, and efficient vehicle. The following sections briefly explain the development of each scenario.

3.1. Business as usual (BAU)

The BAU scenario reflects the projection of the future condition based on the current situation. This scenario is the reference scenario. In this scenario, the projection is based on the currently implemented policies. Therefore, the projection of energy consumption and transportation activity is determined in light of the current trends and policies. The growth of GDP and the population is based on the projection of the National Statistics Council, as shown in Figure. 3. Projections of the growth of GDP and the population are also used in the other scenarios. The composition of used fuel and transportation mode remains the same along the projection period.

3.2. Mode change (MC)

The MC scenario is developed to show the impact of transportation mode change on the projected energy consumption and GHG emissions. The interpolation method is used in the mode change scenario. The mode change is interpolated from the transportation activity per mode from 2015 to 2025 and 2050. The percentage of mode change in 2025 and 2050 is based on the targets of the National Energy Policy of Indonesia. The complete mode change is presented in Table 3.

3.3 Fuel switch (FS)

In 2015, oil-based fuel and a small part of biodiesel are used in the transportation sector. New fuels such as electricity, natural gas, biogasoline, and biojet oil are introduced in the FS scenario. The assumption of the switch between each fuel type in this scenario is presented in Table 4. As it was stated earlier in the introduction, Yogyakarta Province has no installed power plant. All electricity need must be supplied from outside of the region. The emission relate to the use of electricity will be emitted in the outside of the province. Therefore, the emission factor of 0.86 kg CO_2/kWh has been added to this scenario [26]. This emission factor is 2015 value of the interconnection system of Java-Madura-Bali. The electricity system of Yogyakarta Province is within this interconnection system.

3.4. Efficient vehicle (EV)

The EV scenario is based on the use of the new transportation engine technology which is more efficient in terms of fuel consumption. This scenario is

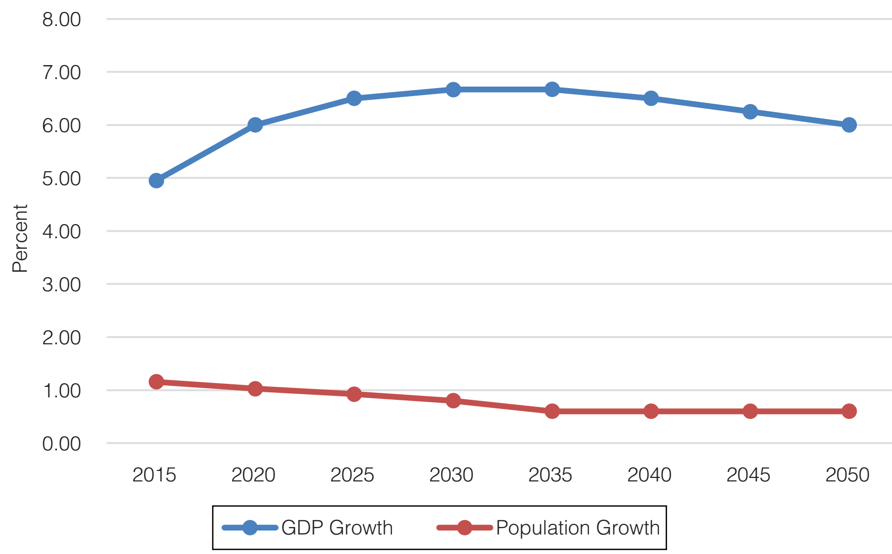

Figure 3: Projections of GDP and population growth

Table 3: Mode change scenario

Mode Change	Unit	2025	2050
Passenger Car to Bus	% from 2015 activity	2.14	7.50
Passenger Car to Train	% from 2015 activity	2.14	7.50
Truck to Cargo Train	% from 2015 activity	4.29	15.00
Motor Cycle to Bus	% from 2015 activity	2.14	7.50
Motor Cycle to Train	% from 2015 activity	2.14	7.50

Table 4: Fuel switch scenario

	Fuel Share (percent)		
Fuel Types	**2015**	**2025**	**2050**
Electricity	–	1.13	2.74
Natural Gas	–	3.06	6.10
Gasoline	72.47	37.03	–
Jet Oil	9.36	9.16	–
Kerosene	–	–	–
Diesel	15.86	2.95	–
Avgas	0.003	0.003	0.003
Biodiesel	2.30	16.50	20.43
Biogasoline	–	27.31	40.84
Biojet oil	–	2.88	29.90

implemented in LEAP by reducing the energy intensity of each fuel type that is used in each transportation mode. As energy intensity reflects the use of fuel per passenger-km, a reduction in energy intensity is directly represented a more efficient transportation engine. The reduction in energy intensity is assumed to be 18% lower at the end of the projection period compared to the based year. The 18% reduction of energy intensity is based on the use of more advance vehicle technology [27].

3.5. GHG mitigation (MIT)

The MIT scenario is a combination of the MC, FS, and EV scenarios and is used to analyze its impact on energy demand and GHG emissions.

4. Results and discussion

This section briefly discusses the results of the simulation of the LEAP model. The discussion is divided into two parts. The first part discusses the projection of energy demand in the transportation sector. GHG emissions that are caused by the fuel used in the transportation sector are discussed in the second part. Each pollutant that contributes to global warming is briefly explained.

4.1. The projection of energy demand

Based on the aforementioned scenarios, the projection of energy demand for the transportation sector in Yogyakarta Province is presented in Figure 4, Figure 5, Figure 6, and Figure 7 for the BAU, MC, FS, and EV scenarios, respectively. The energy demand for the transportation sector in 2015 was 27.33 PJ. In the BAU scenario, the energy demand linearly increases with an average growth of 2.40% annually. Compared to the energy demand in 2015, the energy demand in 2050 increases by 129.34% to 62.69 PJ. The trend in the energy demand projection in the BAU scenario as the result of the continuation scenario with no other intervention of energy-related policy.

A reduction in energy demand can be achieved by the implementation of the MC scenario. The projected energy demand for the transportation sector in the MC scenario is presented in Figure 5. Compared to the results for the BAU scenario, the energy demand in 2050 is 7.62% lower. In this scenario, energy demand in 2025 is 57.91 PJ. Figure 5 also shows that the MC scenario produces the same pattern for fuel types as the BAU scenario.

The implementation of the FS scenario results in different projections of energy demand. This scenario considers all the possibilities of new fuel technology that can be implemented in the transportation sector. The energy demand projections in this scenario are presented in Figure 6 and are the result of using different compositions of fuel types. Compared to the BAU scenario, the total amount of energy consumption in the FS scenario is 59.01 PJ, which is only 5.87% lower than the BAU scenario. Gasoline is no longer the dominant

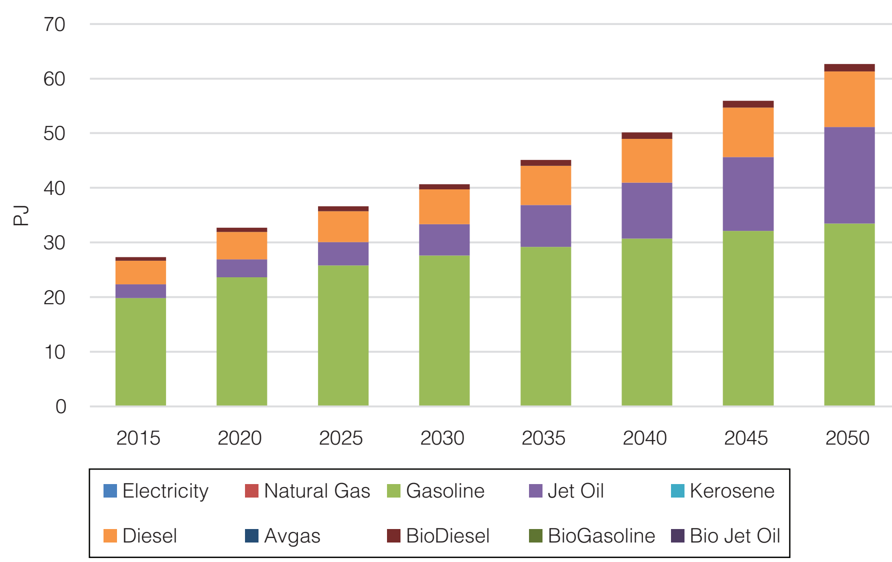

Figure 4: Energy demand for the transportation sector in the BAU scenario

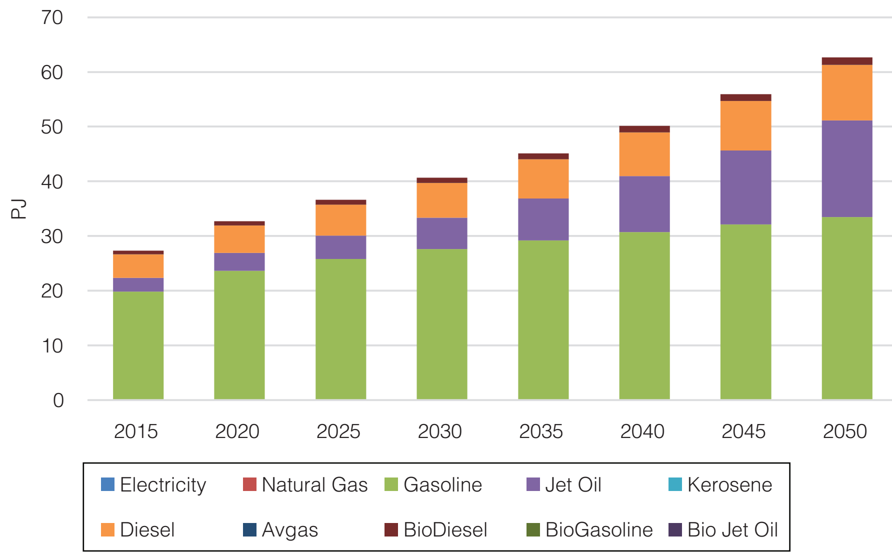

Figure 5: Energy demand for the transportation sector in the MC scenario

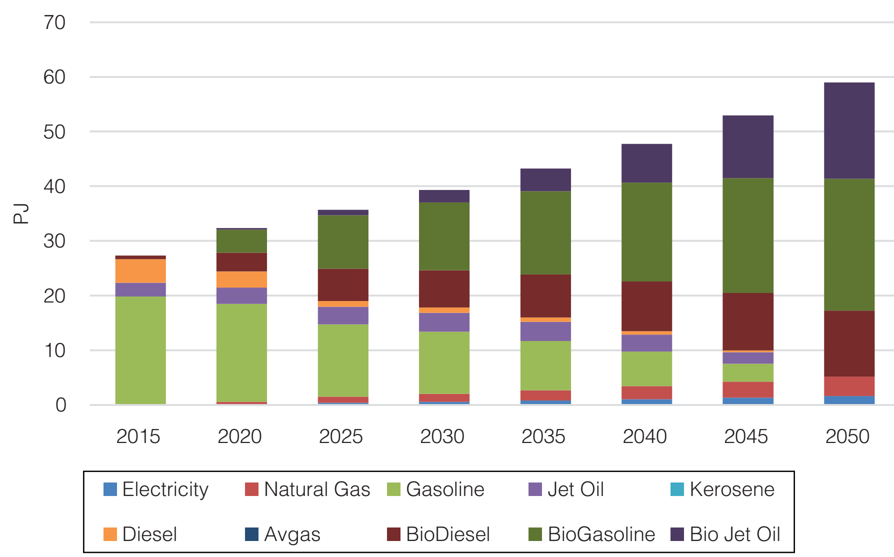

Figure 6: Energy demand for the transportation sector in the FS scenario

fuel over the projection period, rather, this fuel has been replaced by biogasoline which is mostly used in road transport. In 2050, the demand for biogasoline will reach 24.10 PJ. Other bio-fuels used in the FS scenario are biodiesel and biojet oil, with the demand in 2050 being 12.05 PJ and 17.64 PJ, respectively.

A more significant reduction in energy demand can be achieved by the implementation of the EV scenario which results in the energy demand for the transportation sector reducing to 52.77 PJ in 2050 which is 15.82% less than the energy demand in the BAU scenario. However, the implementation of the EV scenario does not result in a different composition of fuel type for the transportation sector as oil-based fuel still dominates in this projection period. The projection of energy demand in the EV scenario is shown in Figure. 7.

The MC, FS, and EV scenarios are combined to form the MIT scenario. The energy demand projections in the MIT scenario are presented in Figure 8 which shows that a reduction in energy demand and a change in the pattern

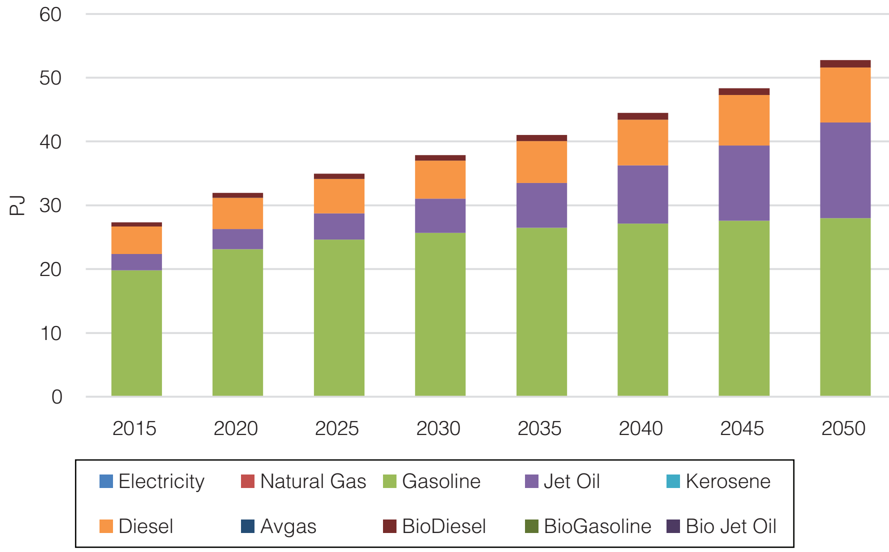

Figure 7: Energy demand for the transportation sector in the EV scenario

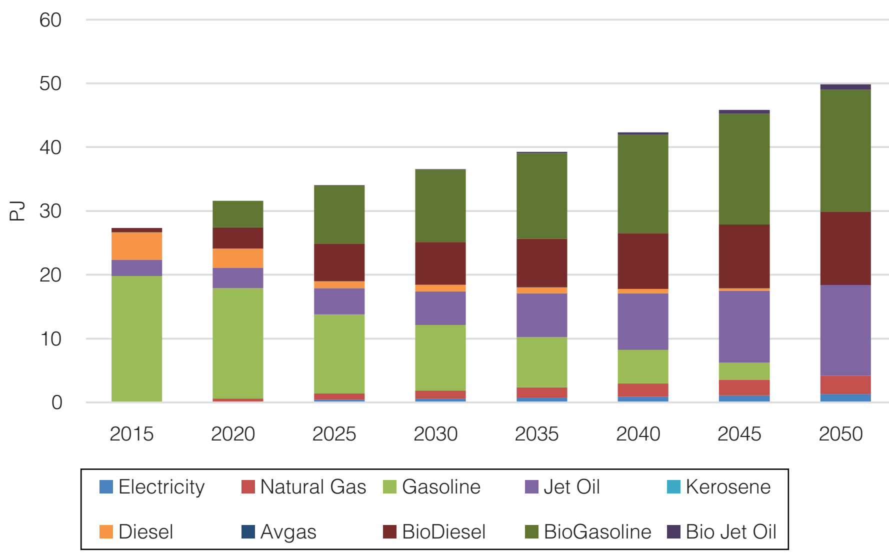

Figure 8: Energy demand for the transportation sector in the MIT scenario

of fuel type can be achieved simultaneously and results in a 20.45% reduction in energy demand compared to the BAU scenario. Energy demand for the transportation sector in 2050 is 49.87 PJ. Moreover, the use of oil-based fuel is reduced significantly. Biofuel starts to dominate the type of fuel used in the transportation sector in 2020. At the end of the projection period, the demand for biofuel is 31.44 PJ or 63.05% of the total fuel consumed in the MIT scenario. The oil-based fuel most used in 2050 is jet oil for air transport at 14.24 PJ.

Table 5 details the reduction in energy demand for the transportation sector by scenario and the percentage of reduction compared to the BAU scenario, showing the potential to reduce energy demand in the transportation sector in Yogyakarta Province. The EV scenario achieves the highest reduction in energy demand along the projection period. In 2050, a reduction of 9.92 PJ is achieved by the EV scenario which is 15.82% lower than the BAU scenario. At the end of the projection period, the MC and FS scenarios reduce energy demand by

Table 5: Comparison of the reduction in energy demand based on the BAU scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Business as Usual (PJ)	27.33	32.71	36.63	40.66	45.10	50.15	55.95	62.69
Fuel Switch (PJ)	27.33	32.34	35.71	39.30	43.26	47.76	52.95	59.01
Reduction (PJ)	*0.00*	*0.37*	*0.93*	*1.36*	*1.84*	*2.39*	*3.00*	*3.68*
Percentage of Reduction (%)	*0.00*	*1.14*	*2.53*	*3.34*	*4.09*	*4.76*	*5.36*	*5.87*
Efficient Vehicle (PJ)	27.33	31.97	34.97	37.89	41.01	44.46	48.35	52.77
Reduction (PJ)	*0.00*	*0.74*	*1.67*	*2.77*	*4.09*	*5.69*	*7.60*	*9.92*
Percentage of Reduction (%)	*0.00*	*2.28*	*4.55*	*6.82*	*9.08*	*11.34*	*13.59*	*15.82*
Mode Change (PJ)	27.33	32.26	35.64	39.03	42.78	47.07	52.06	57.91
Reduction (PJ)	*0.00*	*0.46*	*1.00*	*1.63*	*2.32*	*3.08*	*3.89*	*4.77*
Percentage of Reduction (%)	*0.00*	*1.40*	*2.72*	*4.00*	*5.15*	*6.14*	*6.96*	*7.62*
GHG Mitigation (PJ)	27.33	31.57	34.03	36.55	39.27	42.32	45.82	49.87
Reduction (PJ)	*0.00*	*1.14*	*2.60*	*4.11*	*5.83*	*7.82*	*10.13*	*12.82*
Percentage of Reduction (%)	*0.00*	*3.50*	*7.11*	*10.10*	*12.93*	*15.60*	*18.11*	*20.45*

7.62% and 5.87%, respectively. However, the MIT scenario has the greatest impact on the reduction in energy demand. For all the projections from 2015 to 2050, the MIT scenario achieves a higher level of fuel reduction compared to the other scenarios. In 2050, the MIT scenario results in a reduction of 12.82 PJ which is 20.45% less than the BAU scenario.

In summary, the different scenarios reduce the projected energy demand and dependence on oil-based fuel in the transportation sector in Yogyakarta Province compared to the BAU scenario by varying amounts which is important as the transportation sector consumes the most fuel compared to all other sectors. It should be noted that the projection results for energy demand are exposed to several uncertainties due to certain assumptions in relation to some variables. As an example, the load factor of the vehicle is assumed to be constant and remains the same during the projection period. This might not be the situation as the load factor is likely to change as the population grows. However, for planning purposes, the projected energy demand gives a good overview of fuel consumption in the transportation sector in Yogyakarta Province and will enable policy makers to compare fuel usage in the different scenarios.

4.2. The projection of GHG emissions

CO_2, NO_x, and CH_4 are the gasses emitted by the transportation sector which directly contribute to global warming. This section briefly explains each emitted gas and combine these gasses as GWP factor for all the scenarios.

4.2.1. Carbone dioxide (non-biogenic) (CO_2) emissions

The projected CO_2 emissions from 2015 to 2050 are shown in Figure 9. In 2015, all scenarios emitted CO_2 gas of 1,918.07 thousand ton. In 2050, the CO_2 emissions in the BAU scenario reached 4,423.92 thousand ton, which represents an annual growth rate of 2.42%. In contrast, the projected CO_2 emissions produced by the MC, FS, and EV scenarios in 2050 are 3,724.69 thousand ton, 3,982.92 thousand ton, and 4,096.06 thousand ton, respectively. CO_2 emissions in the MC, FS, and EV scenarios grow at an annual rate of 2.19%, 2.11%, and 1.91%, respectively. The projected CO_2 emissions produced by the MIT scenario in 2050 are 3,329.49 thousand ton, which is an annual growth of 0.89% and is 24.74% lower than the BAU scenario.

4.2.2 Nitrogen oxide (NOx) emissions

The projected NO_x emissions from 2015 to 2050 are presented in Figure 10. In 2015, all the scenarios emitted 16.25 ton of NO_x. In 2050, the volume of NO_x emissions produced in the BAU scenario is 37.32 ton, with an annual growth rate of 2.40%. However, it is projected that in 2050, the MC, FS, and EV scenarios will emit 34.50 ton, 29.12 ton, and 31.41 ton of NO_x with an annual growth rate of 2.17%, 1.68%, and 1.90%

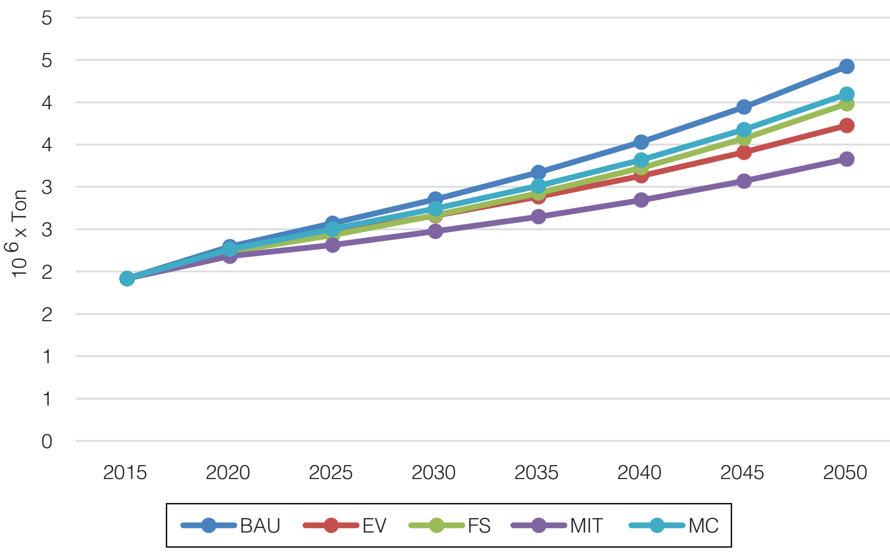

Figure 9: Projected CO_2 emission of the Indonesian transport sector in the different scenarios

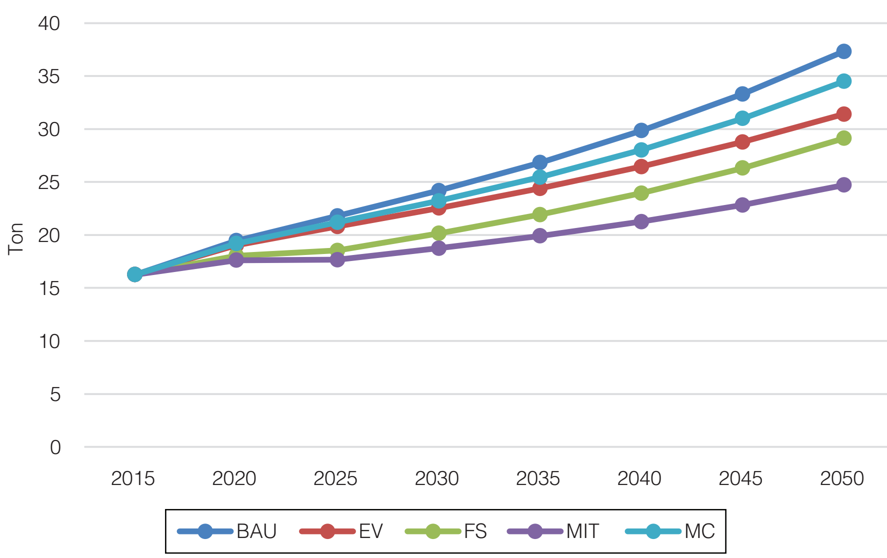

Figure 10: NO_X emissions by scenario

respectively. The lowest emission of NO_x is achieved by a combination of all scenarios. It is projected that the MIT scenario has the lowest NO_x emissions in 2050 at 24.71 ton which is 33.78% lower than the BAU scenario, having an annual growth rate of 1.21%.

4.2.3. Methane (CH_4) emissions

In 2015, all the scenarios emit 81.99 ton of CH_4. The projected emission values of CH_4 from 2015 to 2050 are presented in Figure 11. The annual growth rate of CH_4 emissions in the BAU scenario is 2.40%, resulting in projected CH_4 emissions in 2050 of 188.05 ton. The projected CH_4 emissions in 2050 for the MC, FS, and EV scenarios are 173.73 ton, 164.96 ton, and 158.29 ton, with an annual growth rate of 2.17%, 2.02%, and 1.90%, respectively. However, the MIT scenario results in CH_4 emissions of 139.96 ton in 2050 which is 25.57% lower than the BAU scenario.

4.2.4. Global warming potential (GWP)

Global warming potential (GWP) reflects the combined impact of CO_2, NO_x, and CH_4 emissions on the atmosphere. GWP is expressed in CO_2 equivalent. The projection of GWP caused by CO_2, NO_x, and CH_4

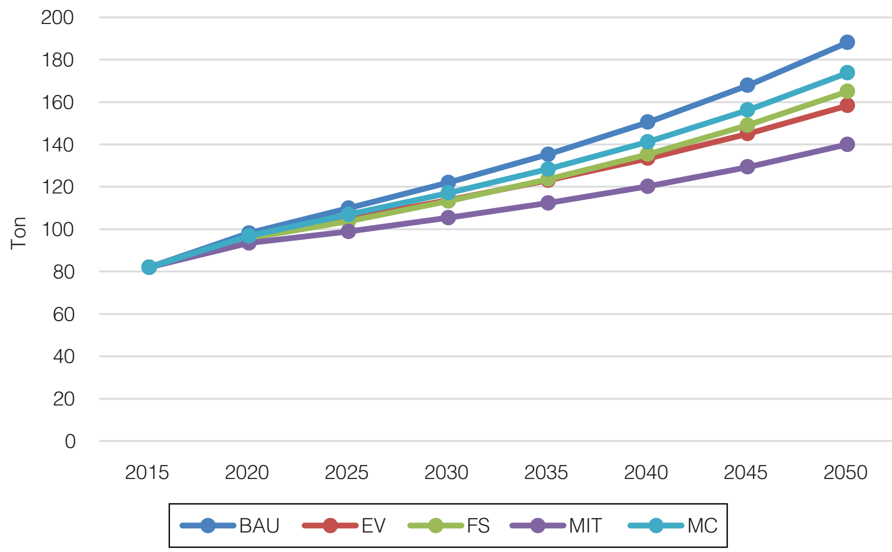

Figure 11: CH_4 emissions by scenario

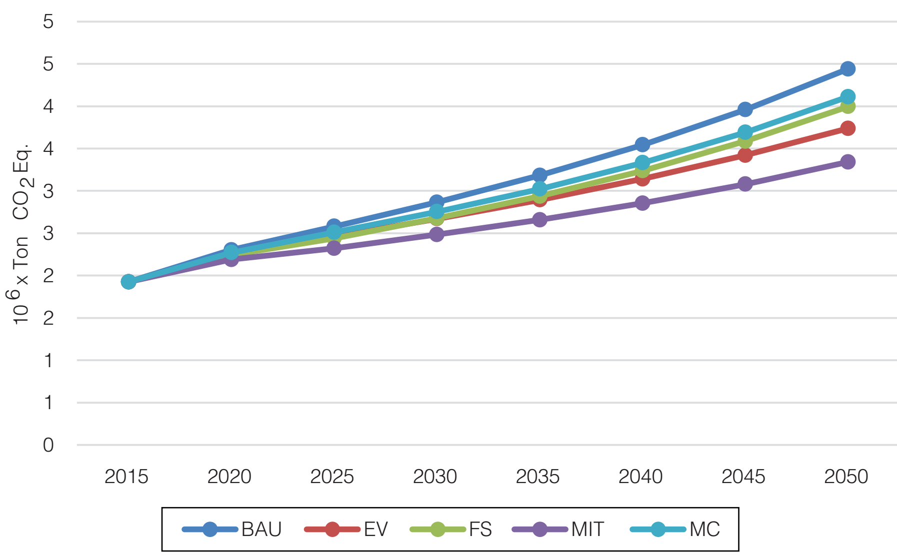

Figure 12: Global warming potential by scenario

gases under the different scenarios is presented in Figure 12. The total GWP produced by the BAU scenario in 2050 is 4,439.45 thousand ton CO_2 equivalent. The GWP for the MC, FS, and EV scenarios in 2050 is 4,110.42 thousand ton CO_2 equivalent, 3,995.58 thousand ton CO_2 equivalent, and 3,737.76 thousand ton CO_2 equivalent, respectively. However, the GWP for the MIT scenario in 2050 is 3,340.24 thousand ton CO_2 equivalent, which is 24.76% lower than the BAU scenario.

In summary, the EV scenario achives the highest reduction in CO_2 and CH_4 emissions, followed by the FS and MC scenarios. The highest reduction of NO_x pollutants is achieved by the FS scenario, followed by the EV and MC scenarios. The EV scenario achieves the highest reduction of GWP. However, the MIT scenario achieves the lowest emissions for all pollutants and has the lowest GWP.

5. Conclusion

The transportation sector in Yogyakarta Province has the highest energy demand compared to all other economic sectors in this province. As a consequence, the transportation sector is the foremost contributor to GHG pollutants. Therefore, it is critical that the transportation sector plays a primary role in reducing its energy demand and GHG emissions in Yogyakarta Province. This study presented the energy demand projections and the projected GHG emissions for the transportation sector of Yogyakarta Province from 2015 to 2050. Four scenarios and a combined scenario were implemented in the LEAP model to evaluate the various policies to reduce the projected energy demand and GHG emissions.

The projection results indicate that, without the intervention of new policies, the energy demand for the transportation sector in 2050 will be 2.29 times greater compared to the total energy demand in 2015. However, by implementing the MIT scenario, the projected energy demand for the transportation sector is reduced by 20.45%. In relation to the other scenarios, the EV scenario achieves the highest reduction in energy demand of 15.82% compared to the BAU scenario, followed by the MC and FS scenarios. On the other hand, the MIT scenario significantly reduces GHG emissions, achieving a 24.76% reduction in GWP compared to the BAU scenario.

The outcomes of this study may be useful for policymakers to analyze and compare energy-related policies for the transportation sector in Yogyakarta Province. All the developed scenarios reduce the demand for oil-based fuel. Therefore, in light of these results, policymakers should be able to propose an energy policy to achieve energy security for the region. Also, the results of this study can contribute to policy design relating to transportation mode changes, efficient vehicles, and biofuel production. Furthermore, these policies can also contribute to pollution control and GHG emission mitigation.

A technical engineering approach which focuses on the effect of the various scenarios in relation to energy demand and GHG emissions was applied in this study. Cost efficiency and cost-benefit analysis were not considered in this study. Therefore, this study can be extended in the future by including a cost analysis of the different scenarios compared to the reference scenario. An economic feasibility study which relates to biofuel production for the transportation sector can also be conducted based on the results of this study.

Reference

[1] Statistic Indonesia, "Growth Rate of Gross Regional Domestic Product," *Statistics Indonesia*, 2018, https://www.bps.go.id/dynamictable/2015/10/07/961/-seri-2010-laju-pertumbuhan-produk-domestik-regional-bruto-atas-dasar-harga-konstan-2010-menurut-provinsi-2010-2017-persen-.html.

[2] Statistic Indonesia, "Population Growth Rate by Province," *Statistics Indonesia*, 2018, https://www.bps.go.id/statictable/2009/02/20/1268/laju-pertumbuhan-penduduk-menurut-provinsi.html.

[3] CASINDO, "Regional Energy Profile of Yogyakarta Province," 2008, pp. 1–6, http://www.casindo.info/fileadmin/casindo/Output_and_deliverables/D23-Yogyakarta-final.pdf.

[4] M. Sadeghi and H. Mirshojaeian Hosseini, "Integrated energy planning for transportation sector-A case study for Iran with techno-economic approach," *Energy Policy*, *vol. 36*, no. 2, 2008, pp. 850–866, https://doi.org/10.1016/j.enpol.2007.10.020.

[5] N. Juul, G. Pantuso, J. E. B. Iversen, and T. K. Boomsma, "Strategies for Charging Electric Vehicles in the Electricity Market," *International Journal of Sustainable Energy Planning and Management*, *vol. 7*, 2015, pp. 67–74, http://dx.doi.org/10.5278/ijsepm.2015.7.6.

[6] H. Achour and M. Belloumi, "Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the LMDI method," *Transport Policy*, *vol. 52*, 2016, pp. 64–71, http://dx.doi.org/10.1016/j.tranpol.2016.07.008.

[7] B. Wang, Y. Sun, Q. Chen, and Z. Wang, "Determinants analysis of carbon dioxide emissions in passenger and freight transportation sectors in China," *Structural Change and Economic Dynamics*, 2018, pp. 6–11, https://doi.org/10.1016/j.strueco.2018.08.003.

[8] S. Hong, Y. Chung, J. Kim, and D. Chun, "Analysis on the level of contribution to the national greenhouse gas reduction target in Korean transportation sector using LEAP model," *Renewable and Sustainable Energy Reviews*, *vol. 60*, 2016, pp. 549–559, http://dx.doi.org/10.1016/j.rser.2015.12.164.

[9] Deendarlianto *et al.*, "Scenarios analysis of energy mix for road transportation sector in Indonesia," *Renewable and Sustainable Energy Reviews*, *vol. 70*, no. 2, 2017, pp. 13–23, http://dx.doi.org/10.1016/j.rser.2016.11.206.

[10] R. Bramstoft and K. Skytte, "Decarbonizing Sweden ' s energy and transportation system by 2050," *International Journal of Sustainable Energy Planning and Management*, *vol. 14*, no. 0, 2017, pp. 3–20, https://journals.aau.dk/index.php/sepm/article/view/1828/1571.

[11] M. T. Brozynski and B. D. Leibowicz, "Decarbonizing power and transportation at the urban scale: An analysis of the Austin, Texas Community Climate Plan," *Sustainable Cities and Society*, *vol. 43*, no. February, 2018, pp. 41–54, https://linkinghub.elsevier.com/retrieve/pii/S2210670718303494.

[12] F. Ülengin, M. Işık, Ş. Ö. Ekici, Ö. Özaydın, Ö. Kabak, and Y. İ. Topçu, "Policy developments for the reduction of climate change impacts by the transportation sector," *Transport Policy*,

vol. 61, no. September 2017, 2018, pp. 36–50, https://doi.org/10.1016/j.tranpol.2017.09.008.

[13] A. L. Paladugula *et al.*, "A multi-model assessment of energy and emissions for India's transportation sector through 2050," *Energy Policy*, *vol. 116*, no. February, 2018, pp. 10–18, https://doi.org/10.1016/j.enpol.2018.01.037.

[14] S. Park, H. Kim, B. Kim, and D. G. Choi, "Comprehensive analysis of GHG emission mitigation potentials from technology policy options in South Korea's transportation sector using a bottom-up energy system model," *Transportation Research Part D: Transport and Environment, vol. 62,* no. March, 2018, pp. 268–282, https://doi.org/10.1016/j.trd.2018.03.007.

[15] M. Tayarani, A. Poorfakhraei, R. Nadafianshahamabadi, and G. Rowangould, "Can regional transportation and land-use planning achieve deep reductions in GHG emissions from vehicles?," *Transportation Research Part D: Transport and Environment, vol. 63,* no. May, 2018, pp. 222–235, https://doi.org/10.1016/j.trd.2018.05.010.

[16] C. Feng and M. Wang, "Analysis of energy efficiency in China's transportation sector," *Renewable and Sustainable Energy Reviews, vol. 94,* no. October 2017, 2018, pp. 565–575, https://doi.org/10.1016/j.rser.2018.06.037.

[17] C. G. Heaps, "Long-range Energy Alternative Planning (LEAP) Systems. [Software version: 2018.1.18]," 2016.

[18] W. Cai, C. Wang, J. Chen, K. Wang, Y. Zhang, and X. Lu, "Comparison of CO2 emission scenarios and mitigation opportunities in China's five sectors in 2020," *Energy Policy, vol. 36,* no. 3, 2008, pp. 1181–1194, https://doi.org/10.1016/j.enpol.2007.11.030.

[19] S. Park, S. Lee, S. J. Jeong, H. J. Song, and J. W. Park, "Assessment of CO2emissions and its reduction potential in the Korean petroleum refining industry using energy-environment models," *Energy, vol. 35,* no. 6, 2010, pp. 2419–2429, http://dx.doi.org/10.1016/j.energy.2010.02.026.

[20] V. Letschert, L. B. Desroches, J. Ke, and M. McNeil, "Energy efficiency - How far can we raise the bar? Revealing the potential of best available technologies," *Energy, vol. 59,* 2013, pp. 72–82, http://dx.doi.org/10.1016/j.energy.2013.06.067.

[21] D. N. Jelic, D. R. Gordic, M. J. Babic, D. N. Koncalovic, and V. M. Sustersic, "Review of existing energy management standards and possibilities for its introduction in Serbia," Thermal Science, vol. 14, no. 3, 2010, pp. 613–623, https://doi.org/10.2298/TSCI091106003J.

[22] Y. Huang, Y. J. Bor, and C. Y. Peng, "The long-term forecast of Taiwan's energy supply and demand: LEAP model application," *Energy Policy, vol. 39,* no. 11, 2011, pp. 6790–6803, http://dx.doi.org/10.1016/j.enpol.2010.10.023.

[23] B. özer, E. Görgün, and S. Incecik, "The scenario analysis on CO2 emission mitigation potential in the Turkish electricity sector: 2006-2030," *Energy, vol. 49,* no. 1, 2013, pp. 395–403, https://doi.org/10.1016/j.energy.2012.10.059.

[24] Anonymous, "National Survey of Energy Consumption of Transportation Sector," 2012, http://calculator2050.esdm.go.id/assets/mini_paper/energy/id/PanduanPenggunauntukSektorTransportasi.pdf.

[25] G. Myhre *et al.*, "Anthropogenic and Natural Radiative Forcing," *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* 2013, pp. 659–740, https://doi.org/10.1017/CBO9781107415324.018.

[26] PLN, "National Master Plan for Electricity Supply," 2015, pp. 2015–2024.

[27] Q. Li, J. Liu, J. Fu, X. Zhou, and C. Liao, "Comparative study on the pumping losses between continuous variable valve lift (CVVL) engine and variable valve timing (VVT) engine," *Applied Thermal Engineering, vol. 137,* no. August 2017, 2018, pp. 710–720, https://doi.org/10.1016/j.applthermaleng.2018.04.017.